Electron Beam Irradiated Intercalated CNT Yarns For Aerospace Applications

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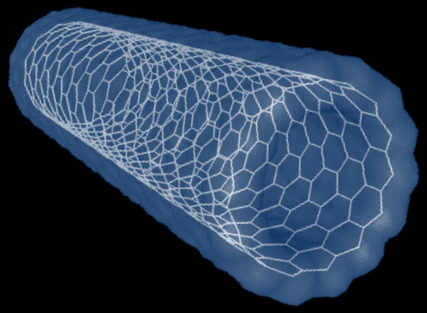


Background and Goals

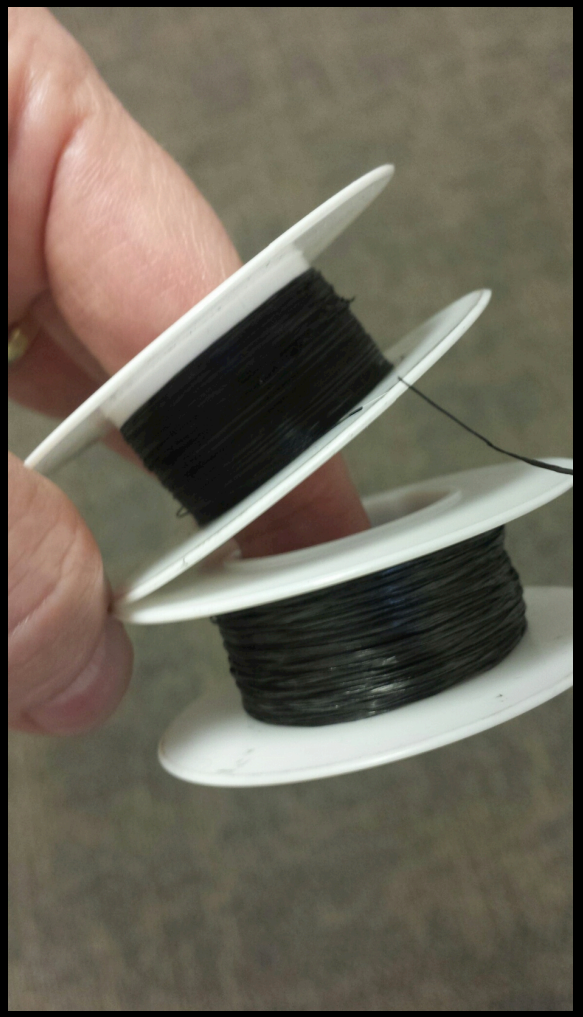
- Previous data suggested that yarns irradiated by an e-beam showed an improvement in tensile properties
- CNT fibers and yarns could potentially be used for multifunctional devices - electrical conductor, data line as well as a tendon for movement
- Electrical conductivity could be doubled with intercalation - 100 kS/cm is needed to equal copper's specific conductivity
- Goal: To determine the effects of intercalation and irradiation on the electrical and mechanical properties of CNT yarns

CNT Fibers

- Nanocomp Technologies NB87 and NB106

  - "(Nanocomp Technology Inc.) production systems generate a "cotton candy" or "stocking-like" flow of millimeter-length CNTs that can be translated into multiple formats, each of which possess a different mix of strength and conductivity", including lightweight wires and yarns

http://www.nanocomptech.com/conductors-and-yarns



Electron Beam

- NEOBeam is an electron beam accelerator owned by Mercury Plastics, Inc. (Middlefield OH)
- It is used to cross-link polymeric materials
- 2 MV electron beam (capable of 5 MV)
- The electrons break C-H bonds and facilitate C-C bonds

http://www.mercuryplastics.com/neo-beam

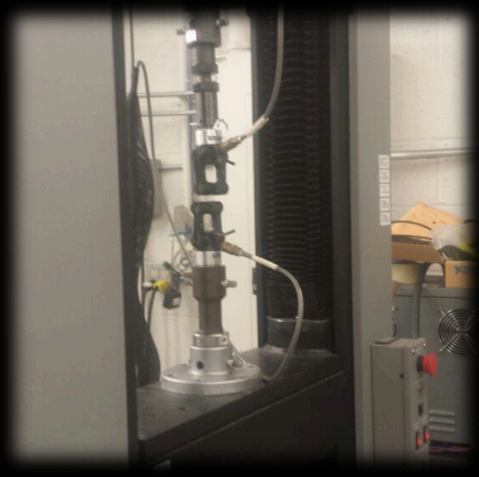
Intercalation of CNT yarns

Test Matrix for NB87 and NB106
As-Received
Intercalated
E-beam for 20 min
E-beam for 40 min
Intercalated then E-beam for 20 min
Intercalated then E-beam for 40 min
E-beam for 20 min then Intercalated
E-beam for 40 min then Intercalated

- Treat CNT fibers in glass reaction vessel with a combination of Bromine, Chlorine and Iodine
- Halogen concentrations and temperatures were held constant for the reactions in the test matrix

Test Equipment

Conductivity – 4-Point Probe Resistance measurement



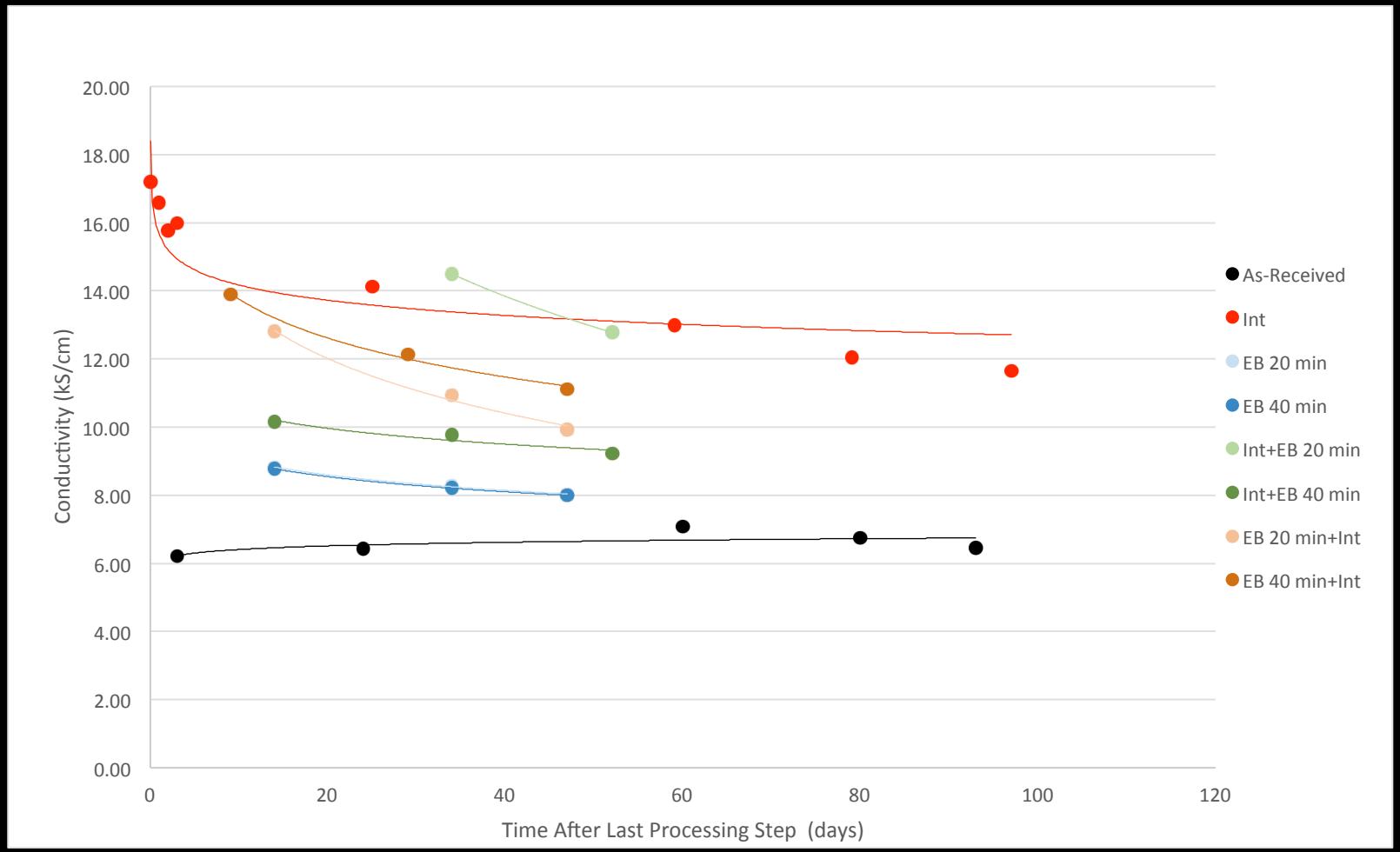
Tensile Testing – Instru-Met Corporation

RENEW 1125

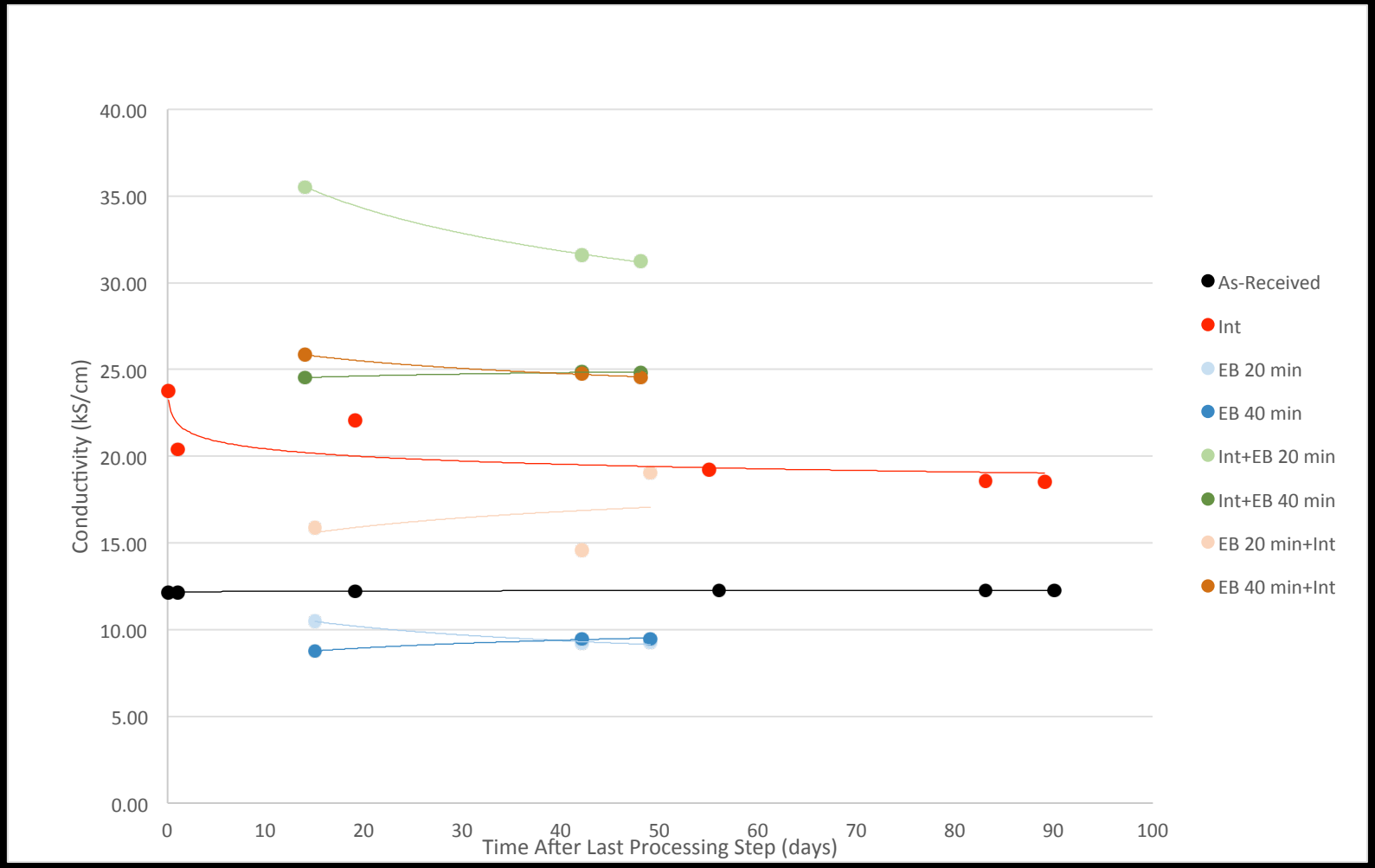
SEM/EDS – Hitachi S-3500N / Thermo Scientific UltraDry 4455D

Raman Spectroscopy - Renishaw System 2000 Microscope with Ar+ ion laser at 514 nm

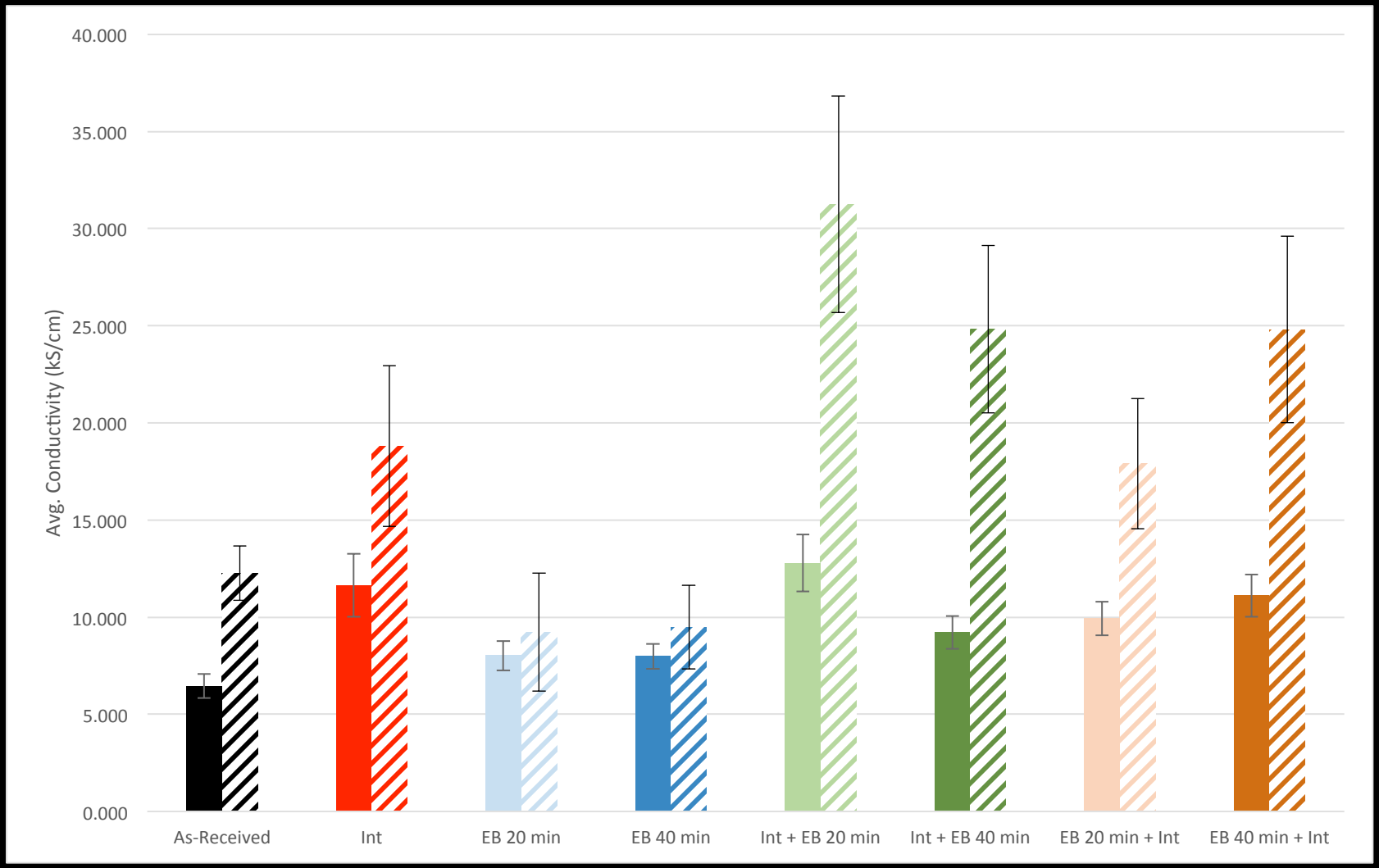
Results – Conductivity With Time – NB87



Results – Conductivity With Time – NB106

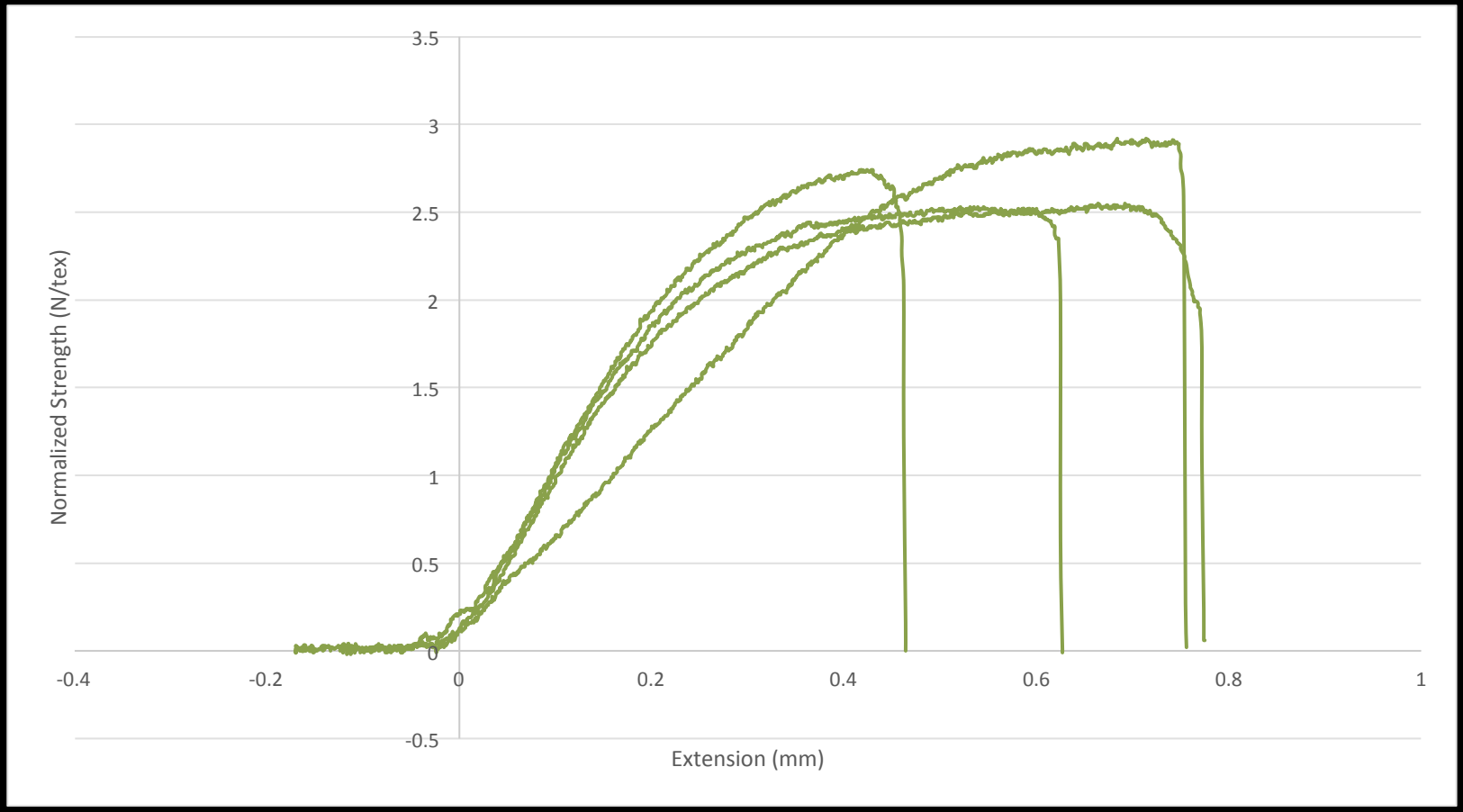


Results – Conductivity (kS/cm)
NB87 (solid) and NB106 (striped)

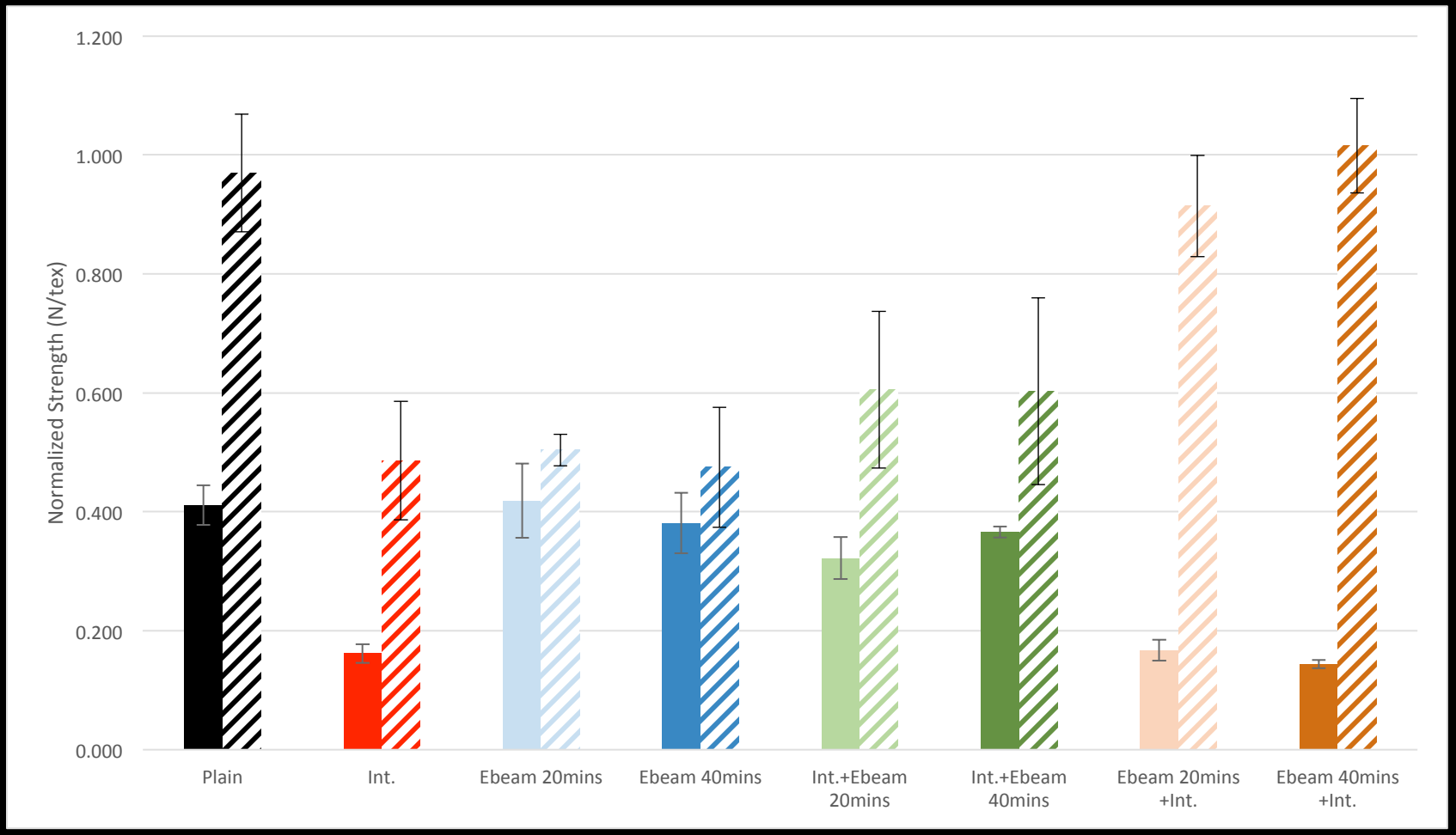


Results – Tensile Test – NB87 Int + E-beam 40 min

4 Samples Tested

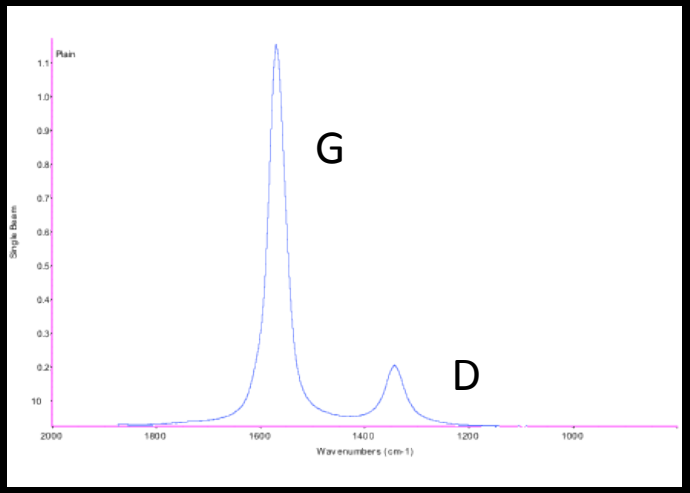


Results – Normalized Strength (N/tex)
NB87 (solid) and NB106 (stripes)

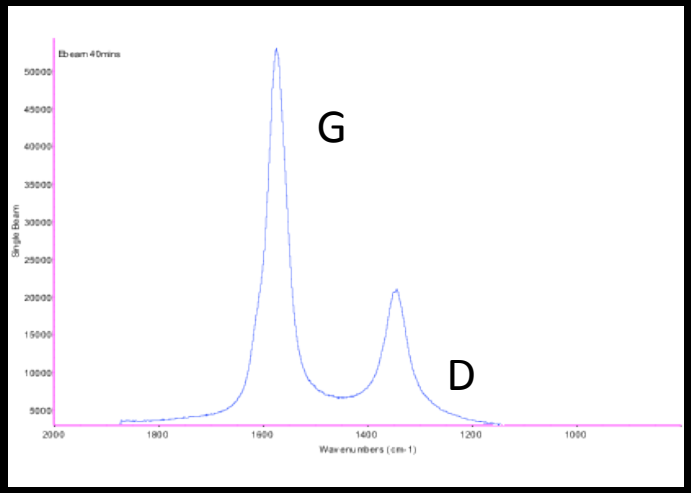


Results - Raman Spectroscopy

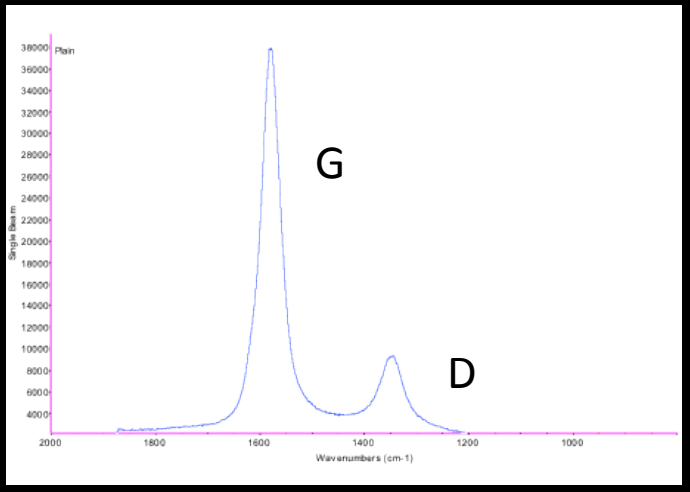
NB87 As-Received



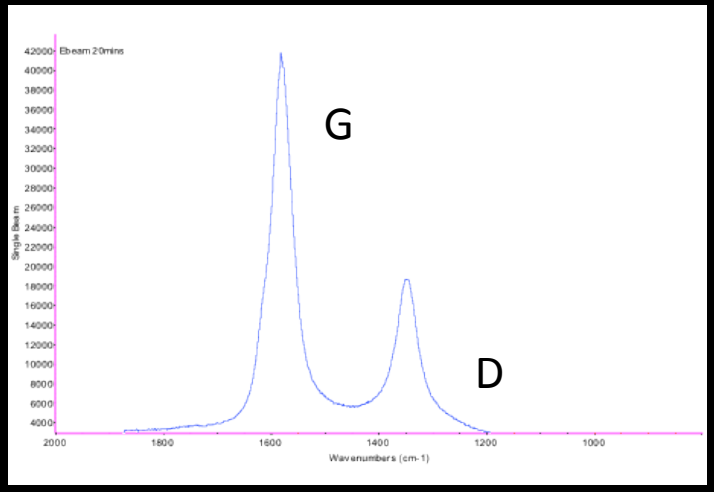
NB87 E-beam 40 min



NB106 As-Received



NB106 E-beam 20 min

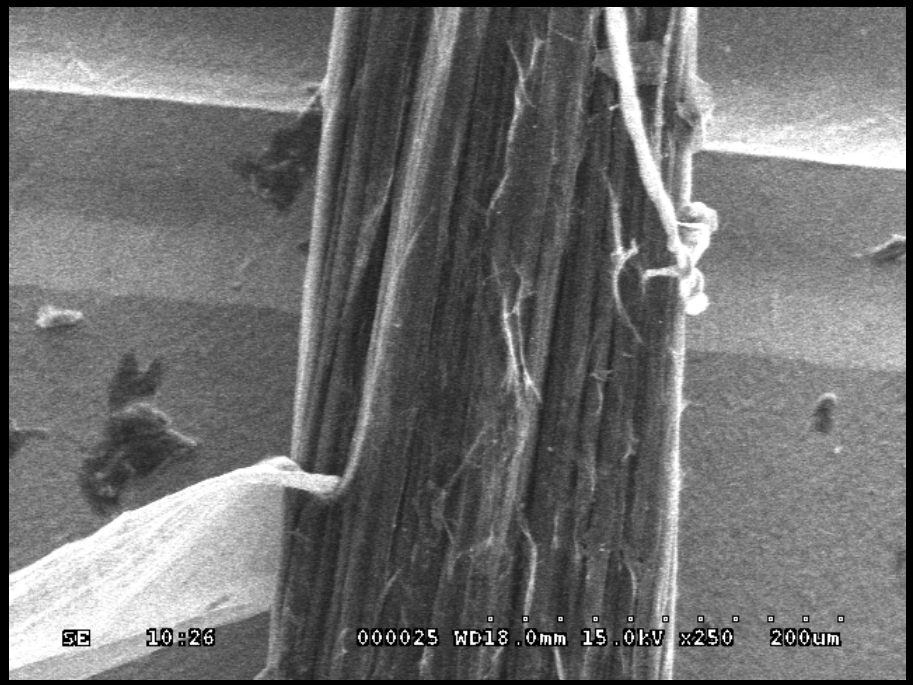


Results – Raman D/G Ratios

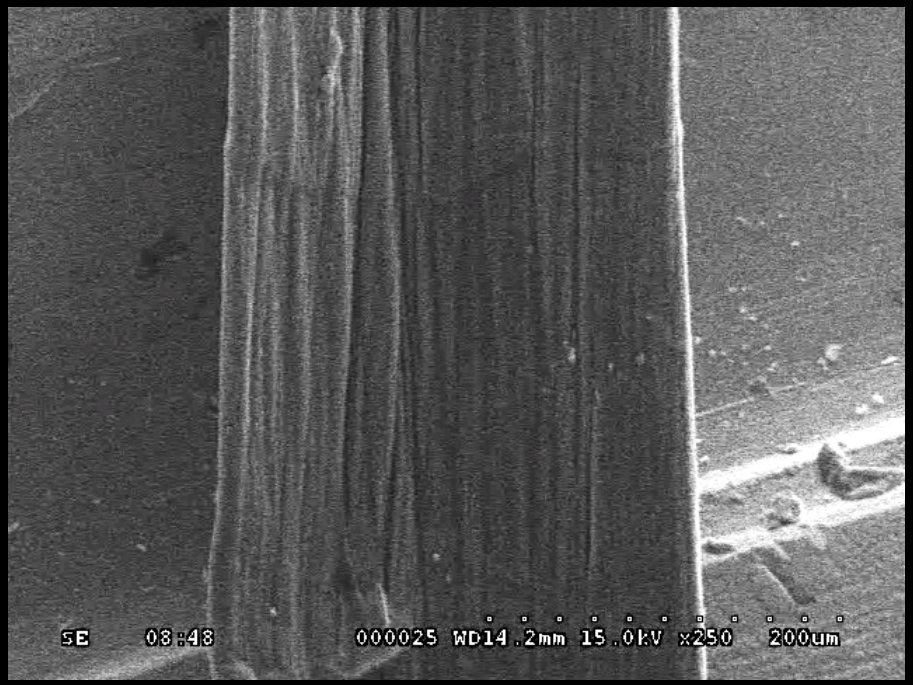
Fiber	As-Received	Int	EB 20 min	EB 40 min	Int + EB 20 min	Int + EB 40 min	EB 20 min + Int	EB 40 min + Int
NB87	0.12	0.28	0.09	0.27	0.22	0.07	0.29	0.23
NB106	0.17	N/A	0.32	0.23	0.21	0.09	0.24	0.28

Results – SEM
NB87

As-Received

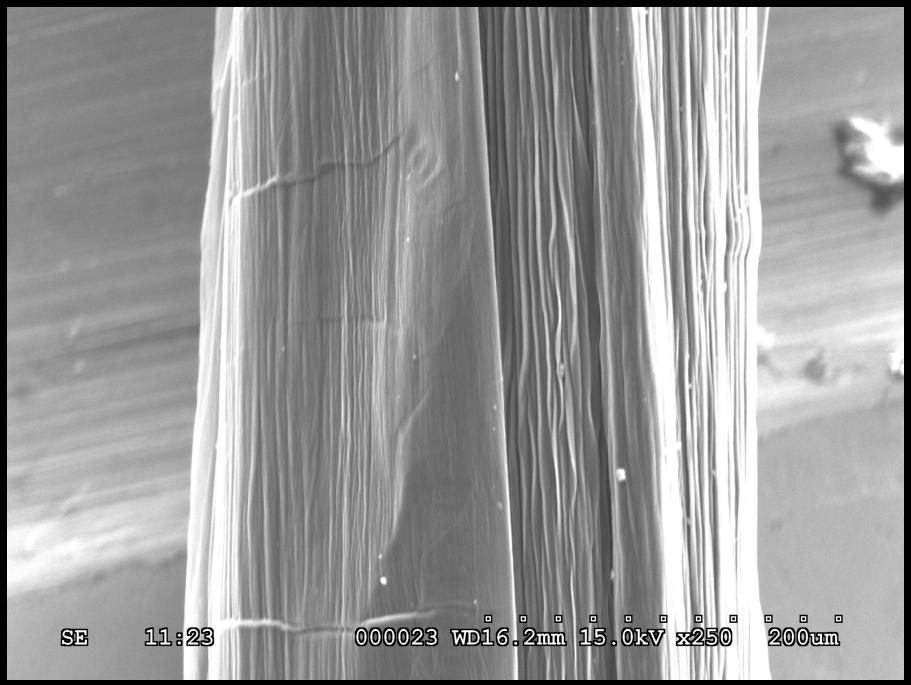


Int + E-beam 20 min

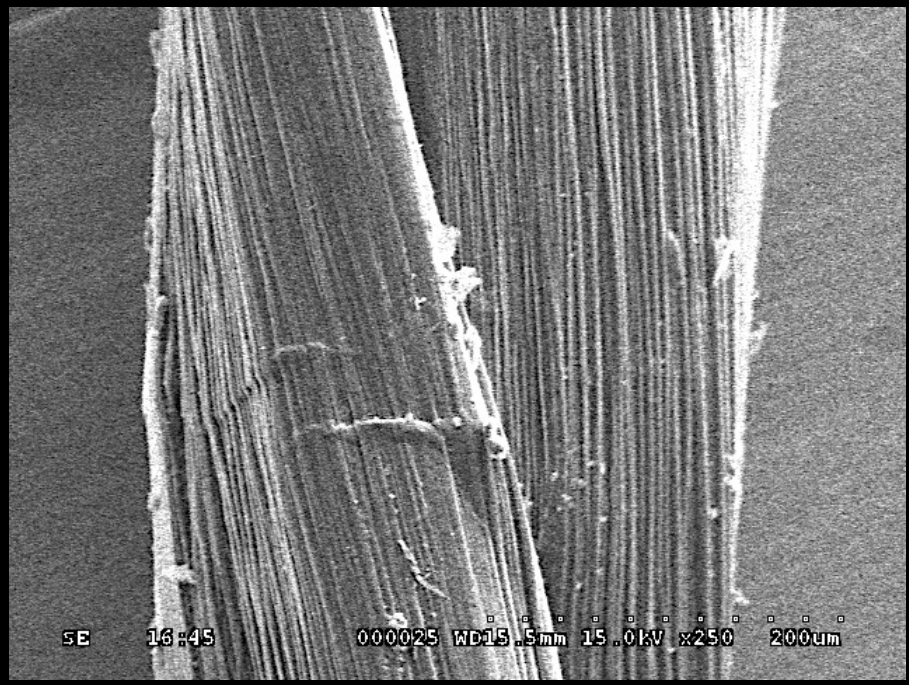


Results – SEM
NB106

As-Received

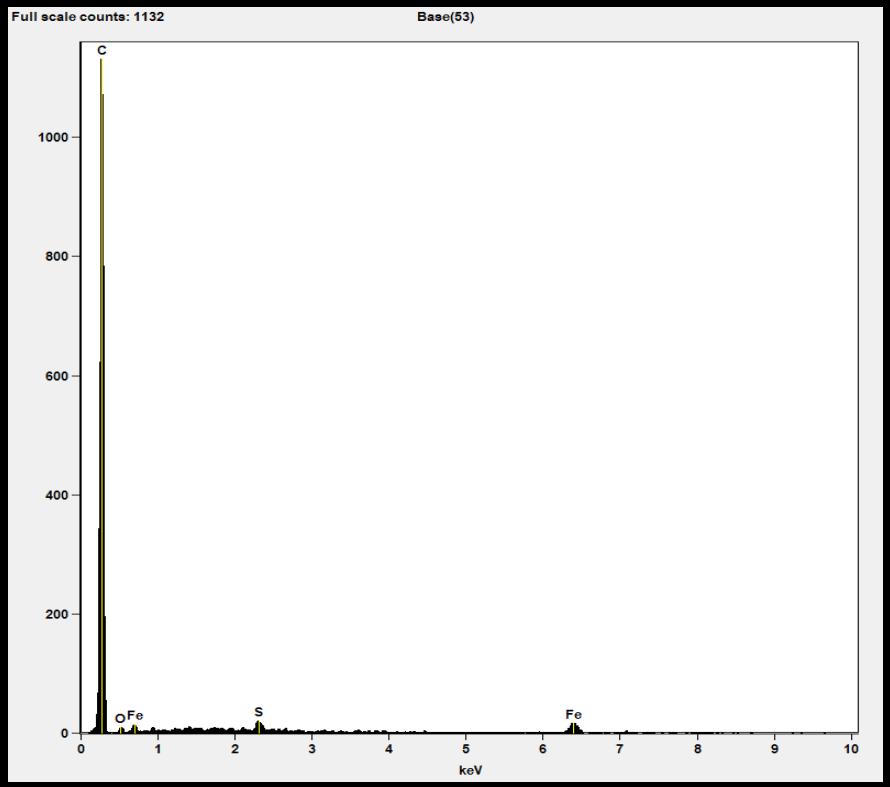


Int + E-beam 20 min

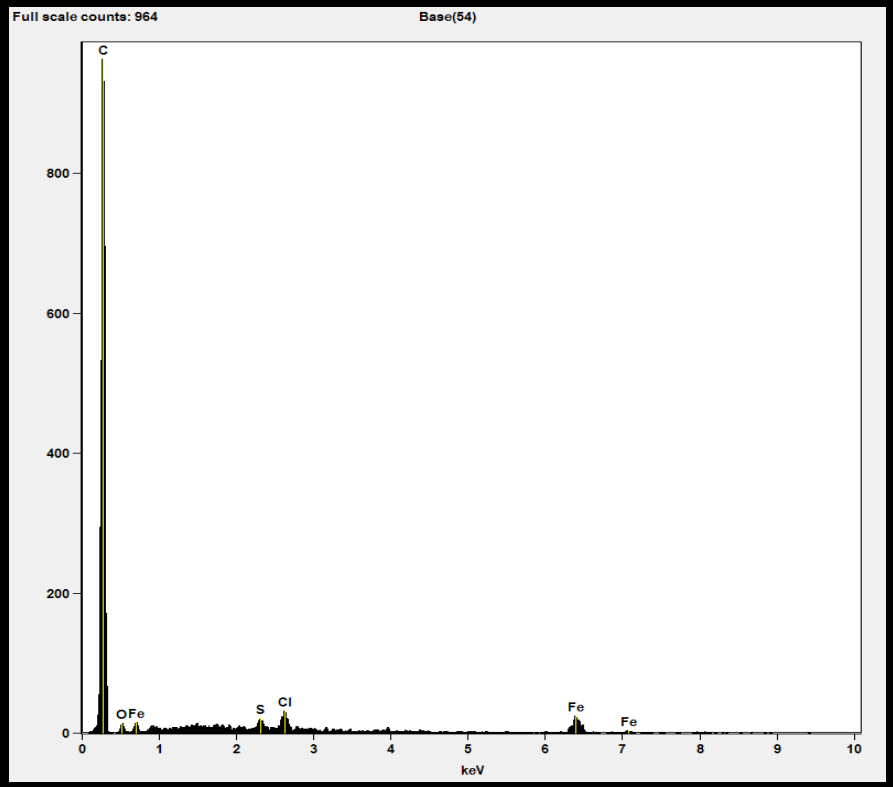


Results – EDS – NB87

As-Received



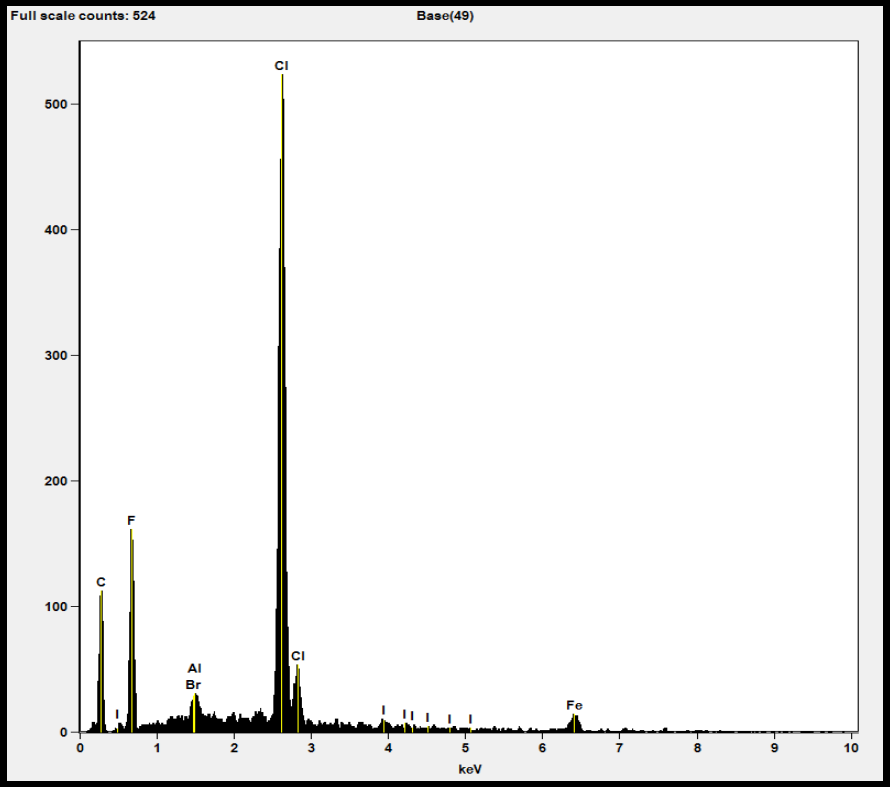
E-beam 20 min



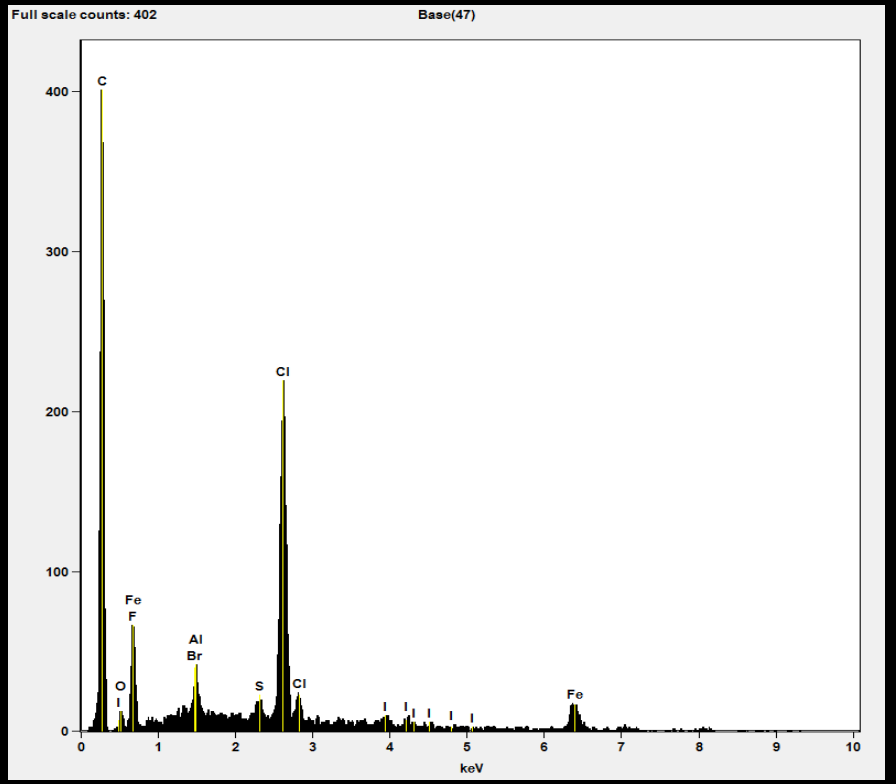
E-beam exposes the chlorine which is used in the manufacturing process

Results – EDS – NB87

Intercalated



Int + E-beam 20 min



Intercalation halogens appear and are reduced after E-beam

Conclusions

- Overall, for CNT electrical wires the NB106 performed better than the NB87 fibers in both conductivity and tensile properties
- Mechanical strength of these particular fibers is not increased with the additional step of the e-beam beyond statistical error, but could help if intercalation is done in some cases
- Conductivity decreases with time in general for these samples
  - NB87 conductivity almost doubles with intercalation, it also shows an increase for any of the other processing steps
  - NB106 conductivity approximately doubles with intercalation, intercalation before and after e-beam also shows an increase in conductivity, e-beam alone shows a decrease in conductivity

Conclusions

- Raman showed some inconsistent results and should be repeated on a different Raman for verification
- SEM generally showed some visual smoothing of NB87 surfaces after processing while the NB106 samples all appeared very similar
- EDS showed consistently that the e-beam removed the halogenated materials unless intercalation took place after the e-beam

Future Work

- Increase the conductivity of the wires through changes in reaction time, concentration and temperature
- In-situ resistance measurements during the reaction process to determine optimum conditions for intercalation
- Coat the intercalated fibers to slow the diffusion of halogens out of the fibers
- Stability of the fibers in other environments such as humidity and changing temperature
- Re-run test matrix samples on another Raman unit

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